

THE ELECTRIC DISCHARGE WITH THE CHLORIDE OF SILVER BATTERY

MESSRS. De La Rue and Müller, in the second part of the researches which they have carried on during three and a half years, have contributed facts of the highest value towards the solution of the problem presented by the beautiful phenomenon of stratification produced by electric discharges in vacuum tubes. The following are some of the more important results of these experiments as described by the authors.¹

These phenomena, first noticed by M. Abria in 1843, were independently re-observed by Mr. (now Sir William) Grove in 1852, and have since engaged the attention of many physicists. The late Mr. Gassiot, working at first with an induction coil, but more recently on the same lines as the voltaic batteries of high potential,² published results of great interest; while, on the other hand, Mr. W. Spottiswoode is still pursuing with great acumen and originality a similar investigation, both with the induction coil and the Holtz machine, with which he has recently used condensers of great capacity.

Throughout our labours we have felt so strongly the necessity of obtaining numerical results as data for the foundation of a theory, that we have not hesitated to risk much in this cause. By the fusion of terminals, or the sudden discharge of the condenser, we have lost a vast number of very beautiful tubes; but gradually by the adoption of various devices, and by the employment of instruments specially constructed and insulated to suit the high potentials we deal with, we have succeeded in overcoming the various impediments, so that we can now readily obtain values for the physical quantities that enter into consideration in our experiments.

There is a serious trouble connected with the study of the discharge in rarefied gases, for, after a very short time, the tubes completely and permanently change, so as no longer to present the splendid stratifications witnessed on a first trial. We believe these changes occur much more rapidly with the battery in consequence of the greater amount of current, than with the induction coil; but the fact appears to have been well known to Dr. Geissler, of Bonn, who, on the occasion of a visit to our laboratory, brought with him some tubes through which no current had previously passed (virgin tubes, as he called them), which presented most beautiful phenomena lost for ever after too brief a period.

Tube 123 (cyanogen), for example, when first connected

with the battery, presented strata which completely filled the tube without leaving a dark space near the negative, some threading themselves on it, as shown on the left of Fig. 1; but after a few seconds the strata widened out as on the right hand figure, then other changes occurred, and the first phases have never been reproduced.

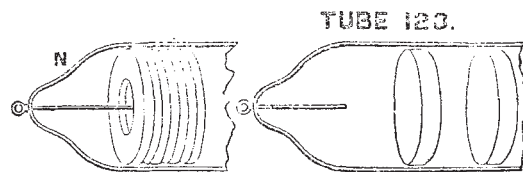


FIG. 1.

Another case is presented by the nitrogen tube Fig. 2, the right-hand figure showing the first phase, and the left-hand figure a second phase, which in its turn has for ever disappeared, and has been replaced by the ordinary disk-form of strata.

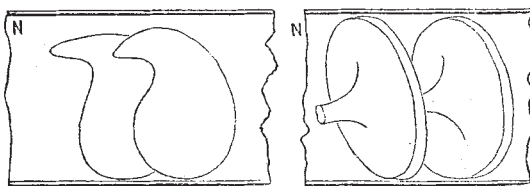


FIG. 2.

After spending much time in experiments with tubes prepared for us by Dr. Geissler, Messrs. Alvergnyat Frères, of Paris, and Mr. Hicks, of Hatton Garden, with the vexation of finding that we could not often enough repeat our experiments, we ultimately came to the conclusion to have others made, but not exhausted, and to perform ourselves the charging and exhaustion. The tubes we usually employ have a glass stop-cock fitted to them at each end; they are 32 inches long, and from 1.75 to 2 inches in diameter; the terminals are of aluminium, and about 29 inches apart, one being a ring, the other a wire bent at a right angle, so as to point in the direction of the axis of the tube (see No. 144, Fig. 3), for we have found that the phenomena vary according as the ring or wire is made positive.



FIG. 3.

These we exhaust and fill with any gas we may wish to experiment with, and gradually exhaust again, noting the phenomena presented at different pressures, with different potentials, and with different amounts of current. We re-fill and exhaust the tube again and again, and mostly obtain, under the same conditions, as nearly as possible the same phenomena, of which we are careful to make sketches and, if possible, to obtain photographic records.

In some cases we make use of tubes provided with a

¹ See *Phil. Trans.*, vol. clxix., pp. 55-121.

² Mr. Gassiot made several batteries of different kinds in the course of his experiments; on the occasion of a visit to his laboratory, January 26, 1875, the current of his Leclanché battery was measured by us with a voltmeter. The current of 1000 new cells was found to be 0.07404 W; that of the whole 3000 cells, 1000 of which had been a long time in use, 0.04718 W. Taking the Leclanché as 1.48 volt the internal resistance of the new battery must have been 19.83 ohms per cell; that of the whole 3000, 31.87 ohms per cell. The striking distance of the whole 3000 between a conical point and a disk 0.125 inch diameter was only 0.125 inch; whence the inference is that the insulation was, at that time, imperfect.

calibrated chamber between two stop-cocks, as *a-b*, No. 145, Fig. 4, the chamber in this particular case having $\frac{1}{2260}$ th of the capacity of the tube, this tube has also an absorption chamber communicating through a cock and intended to contain spongy palladium. After a tube has been exhausted so as to produce a particular phase, and in the course of the experiment the exhaustion has been carried beyond that degree which permits of the reproduction of that phase, one or more charges of gas may be successively admitted into the tube by filling the calibrated chamber with gas at any particular pressure, and then opening the stop-cock communicating with the tube; the last phase is thus reproduced.

The apparatus which we have found it advantageous to adopt for the exhaustion of our tubes is shown in Fig. 5; it comprises three means of exhaustion which are successively employed as the vacuum becomes more perfect. The first is an Alvergnyat high-pressure water *trompe* in connection with the high-pressure water-main of the

West Middlesex Water Company, the head of water being 106 feet; it produces a vacuum to within half-an-inch (0.47 in. = 12 millims.) of the height of the barometer. The pipe leading to it is so marked in the drawing; it is

attached, through a cock, to a four-way-junction-piece *R*, provided with three more cocks, communicating:—one to one end of the tube *T*, one to the last drying bottle of the gas generator *G G'*, and one to a mercurial gauge. The

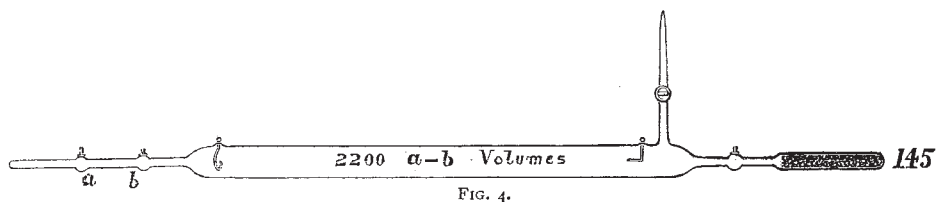


FIG. 4.

other end of the vacuum tube *T* communicates by means of a Y-piece to both, an Alvergriat mercurial pump, on the right of the figure, and a Sprengel pump, on the left. After the *trompe* has done its work, the Alvergriat is used for rapid exhaustion, and then shut off by means of the glass cock *C*, leaving the exhaustion to be completed by the Sprengel; we have thus obtained, by the pumps alone, in tubes 32 inches long and 2 inches in diameter, vacua of only 0.002 millimetre pressure, equal to 2.6 millionths of an atmo-

sphere—a vacuum so perfect that the current of 8040 cells would not pass. The apparatus is in connection with a McLeod gauge, by means of which pressures to 0.00005 mm. can be determined. Besides this gauge, the Sprengel and Alvergriat pumps have their own gauges, which read to a millimetre. *M* is a rotating mirror consisting of a four-sided prism mounted on a horizontal axis and provided with a multiplying wheel; on each face of the prism is fastened a piece of looking-glass. The reflection of the tube in the mirror enables one to examine

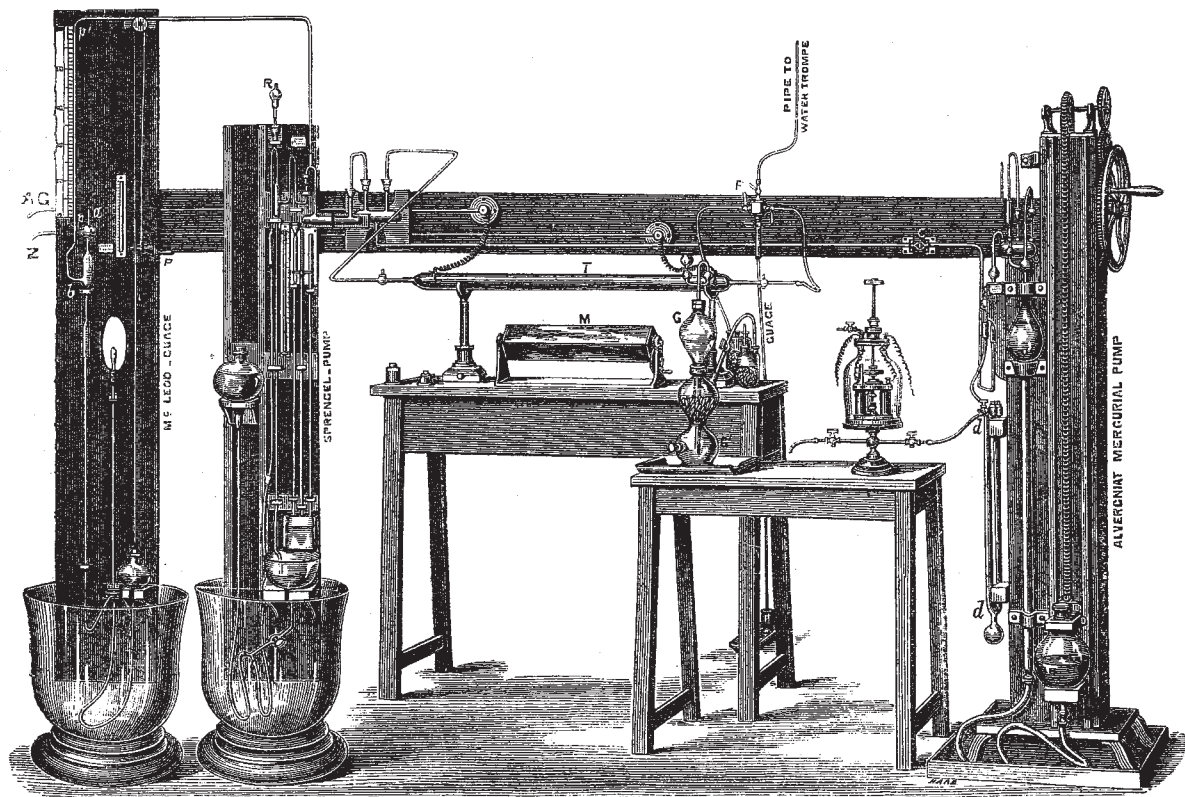


FIG. 5.

whether an apparently nebulous discharge is simply nebulous or consists really of strata, also whether and in what direction there is a flow of strata which may appear quite steady to the eye. The observations are facilitated by covering the tube with a half cylinder of cardboard having a slit in the direction of its axis about $\frac{1}{10}$ inch wide. *R* is a radiometer attached to the Sprengel; *d, d*, a drying tube containing sticks of potash used when gas is introduced from a reservoir through the Alvergriat.

The resistance of vacuum tubes does not depend solely

or mainly on the distance between the terminal, but it does greatly on their diameter.

In order to test how much of this depends on the length of any constriction, we had made two tubes, 154 and 155, Fig. 6, of nearly the same length (16 inches), and internal diameter $\frac{1}{8}$ ths of an inch, the residual gas in each case being carbonic acid, CO_2 . From results obtained with these tubes where the constriction varied in length in the ratio of 125 to 1, it became evident that the main effect is due to the simple constriction of the tube.

The diagram Fig. 7, shows the arrangement by which,

in our early experiments, we measured the resistance of a tube. The tell-tale tube¹ had to be substituted for the galvanometer in the ordinary Wheatstone bridge, as the difference of potential between C and D fluctuated greatly

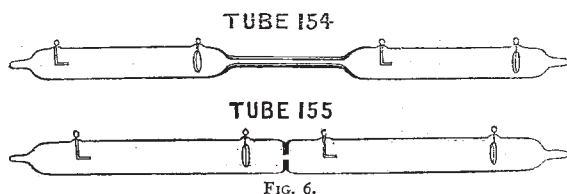


FIG. 6.

in the course of the experiment, causing violent swings of the needle.

A Z is the battery, the A terminal of which is connected at A', in the bridge arrangement, with two equal fluid resistance tubes, FR and FR', of 420,000 ohms, placed in vessels containing ice, to keep them at a constant temperature; an adjustable coil resistance is inserted between B and D; the tube T T', to be tested, is placed between D

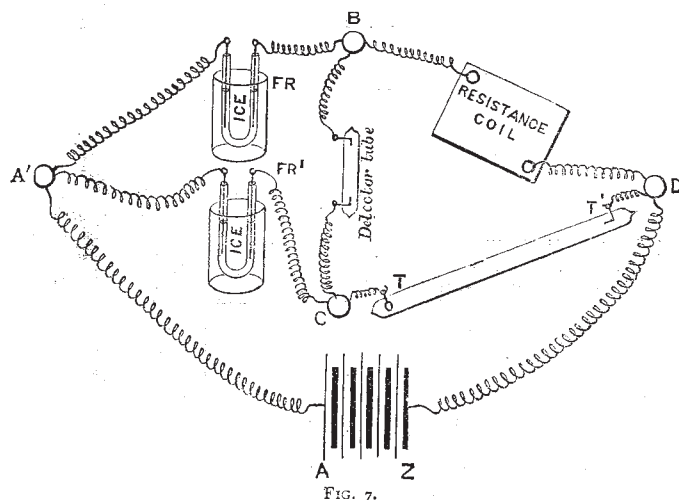


FIG. 7.

and C, the Z terminal of the battery being connected to D. When the resistance is greater or less than that of the tube to be tested there is an illumination in the detector tube between B and C; but when a current passes in T T', balanced by a proper adjustment of the coil resistance, then the glow in the detector ceases. It was ultimately found that the detector tube might be suppressed because, as soon as the resistance in B D is a little in excess of that of the tube, the latter gives evidence by its illumination

of the current passing. After the current in a tube has commenced it is generally found that it will continue to glow, even when some of the balancing resistance, B D, is plugged out in the coil box, showing that when once started the *working* resistance becomes less. If, on the other hand, the current has been stopped entirely, it requires generally a greater balancing resistance in the coil box between B D to start it again than it did in the first instance. After standing for a short or long time it regains its normal condition, but the interval required may amount to several days. The following numbers were obtained:—

Tube	Started with ohms.	Ran up to ohms.	Nature of the Gas.
1	200,000	250,000	
2	350,000	500,000	
6	270,000	500,000	N
42	15,000	70,000	N
81	150,000	infinity.	CO ₂
95	700,000	1,000,000	Si F ₆

Subsequently we found it to be more convenient not to make special determinations of the resistances of the tubes beforehand in the way just described, but to obtain them by reproducing the deflection of a galvanometer, by substituting wire resistances for the tube, or by measurements taken with an electrometer in the manner to be described, while observing the phenomena of stratification.

From measurements thus made with a tube having several rings about 1 inch apart (No. 25, like in Fig. 9), or a Spottiswoode tube with a shifting terminal (No. 147, Fig. 8), we found that the resistance of a vacuum tube, unlike that of a wire, does not increase in the ratio of the distance between the terminals for the same gas at the same pressure.

In making these experiments it was noticed that the resistance for equal distances appeared to be greater in proximity with the negative pole than in other parts of the tube, and fresh experiments were in consequence undertaken to ascertain the potential at the several rings by means of a delicate Thomson-Becker quadrant electrometer furnished with an induction plate, I, Fig. 9, which may be adjusted to any required distance from the quadrant beneath it.¹ The tubes employed among others were No. 25, described above, and two other longer tubes, namely, No. 149 (CO₂) with 12 rings 2 inches apart, and No. 150 (CO₂) with 17 rings also 2 inches distant. The current was led through a metallic resistance to the first ring, the last ring and the other pole of the battery being to earth. It was found that the greatest difference of potential occurs between the last ring and the last but one on the negative side, the next greatest difference being between the last and the last but one on the positive side, but the difference in the former case is far greater than in the latter; in some cases there is little or no difference

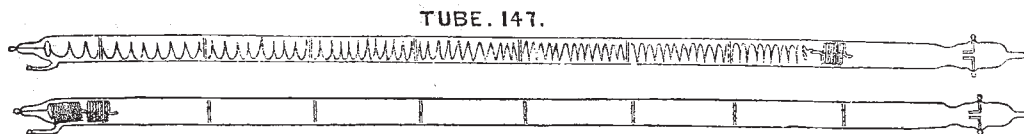


FIG. 8.

in the last but one and the last but two on the negative side; in these cases the last but one on the negative side was dark, while all the others had a luminosity about them. The difference of potential between the rest of the rings is sensibly uniform.

The following observations, made December 21, 1877, with tube 150, may be taken as an illustration of the method of measurement adopted. Batteries 6 and 7

¹ A tube selected for the readiness with which it permits the passage of a current of 440 cells.

(2,400 rod cells) were employed, and adjustable resistances were inserted in circuit for the double purpose of affording the means of readily varying the strength of current without interruption, and of enabling a measurement of that current to be made with the electrometer. The connections are shown in the diagram, Fig. 9.

² It has since been found more advantageous to separate the induction apparatus from the electrometer. Each pair of quadrants is charged with opposite electricities by means of two separate batteries of twenty chloride of silver cells, the opposite poles being to earth; and the induced plate of the induction apparatus communicates with the needle.

The circuit was first broken by removing the earth wire from ring 17, and the plug T, in connection with the induction plate I, being touched at any point between K' and ring I gave the reading for "Full Potential, open circuit;" next, the earth wire was replaced at ring 17, and the value for "Full Potential, closed circuit," was

obtained by causing T to touch at K'. As these batteries had but small internal resistance, the difference between these two readings was scarcely perceptible. By touching T at rings 1, 2, &c., in succession, their potentials were observed. The current was then reversed and similar observations were made. Next, for the purpose of

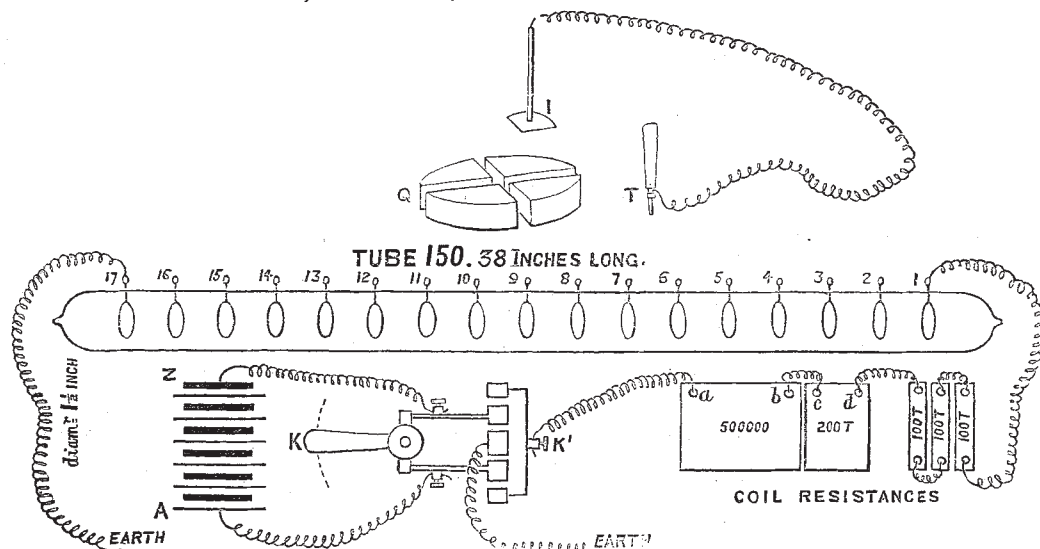


FIG. 9.

making a better examination of the tube in detail, the induction plate I was lowered to that distance which gave as large a deflection for the difference of potential between the two ends of the tube as was convenient. After the potentials of the several rings had been measured in succession with both currents, the induction plate was

restored to its original position, and one or two of the first observations were repeated for confirmation. The current was then varied by altering the resistance in circuit,¹ and fresh measurements made in the same order. Thus the following values were obtained:—

I. CIRCUIT:—2,400 rod-cells, 1 megohm resistance, Tube 150. Induction plate at 2 inches distance from the quadrant

Current +			Current -		
Zero	...	6 right = 0	Zero	...	6 right = 0
Full potential (open circuit)	...	154 left = 160	200	...	194
" (closed ")	...	153 or 4, = 159	198	...	192
Potential at ring 1	...	106 " = 112	133	...	127
" " 2	...	96 " = 102	108	...	102
" " 3	...	not observed	100	...	94
" " 4	...	"	95	...	89
" " 5	...	"	89	...	83
" " 14	...	26 left = 32	not observed	...	127
" " 15	...	20 " = 26	25 right = 19	...	
" " 16	...	16 " = 22	20 " = 14	...	
" " 17	...	6 right = 0	6 " = 0	...	

II. Circuit varied by substituting 800,000 ohms for the 1,000,000 ohms of wire, and inserting liquid resistance No. 3 (2,690,000 ohms) between the wire resistance and ring 1.

Current +			Current -		
Zero	...	5 right = 0	Zero	...	5 right = 0
Full potential (open circuit)	...	159 left = 164	1st Observation.	...	189
" (closed ")	...	159 or 8, = 163	2nd Observation.	...	187
Potential after 800,000 ohms	...	139 " = 144	192	...	186
" at ring 1	...	112 right = 117	167	...	162
" " 2	...	not observed	136	...	131
" " 3	...	"	5	...	0
" " 4	...	"	5 right = 0	...	
" " 15	...	"		...	
" " 16	...	"		...	
" " 17	...	5 right = 0		...	

¹ This method of varying the current is arranged to save time. The circuit must not be interrupted in the course of a set of observations.

III. The induction plate was lowered from 2 inches to $1\frac{1}{2}$ inch. Current —. (The current + was not observed for want of time.)

Ring	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Readings	276	217	200	187	174	159	144	130	116	104	90	76	62	48	35	22	0
Differences		59	17	13	13	15	15	14	14	12	14	14	14	13	13	22	

The observation III. illustrates that which has already been said concerning the fall of potential within the tube.

In case I. we have for the currents in webers—

$$C + = \frac{4.7}{1.88} \times 2400 \times 1.03 = 0.0007261, \text{ and}$$

$$C - = \frac{6.5}{1.88} \times 2400 \times 1.03 = 0.0008281,$$

and for the difference of potential in volts (V) between the two ends of the tube—

$$(C +) V = \frac{11.6}{1.88} \times 2400 \times 1.03 = 1730, \text{ and}$$

$$(C -) V = \frac{12.7}{1.88} \times 2400 \times 1.03 = 1618.$$

These differences of potential would be reproduced if for the tube were substituted metallic resistances in ohms (R)—

$$(C +) R = \frac{11.6}{1.88} \times 1,000,000 = 2,383,000, \text{ and}$$

$$(C -) R = \frac{12.7}{1.88} \times 1,000,000 = 1,954,000.$$

In case II.—

$$C + = \frac{19.5}{1.88} \times 2400 \times 1.03 = 0.0003674, \text{ and}$$

$$C - = \frac{25.5}{1.88} \times 2400 \times 1.03 = 0.0004190.$$

$$(C +) V = \frac{11.6}{1.88} \times 2400 \times 1.03 = 1756, \text{ and}$$

$$(C -) V = \frac{13.2}{1.88} \times 2400 \times 1.03 = 1736.$$

$$(C +) R = \frac{11.6}{1.88} \times 800,000 = 4,780,000, \text{ and}$$

$$(C -) R = \frac{13.2}{1.88} \times 800,000 = 4,142,000.$$

Selecting the observations with the current positive in each case and placing these in juxtaposition thus—

	C		V		R
Case I.	0.0007261	...	1730	...	2,383,000
„ II.	0.0003674	...	1756	...	4,780,000

we see that when C is varied in the ratio of 2 : 1, V remains sensibly constant, R varying as 1 : 2; that is to say, though the current is halved, the difference of potential between the ends of the tube remains constant—a condition which could only be brought about when metallic resistance is substituted for the tube, by doubling this resistance.

This points to the important conclusion that *other things being kept constant* and the current alone varied, we should find the value of V *strictly* constant for all values of C ; but it may readily be imagined that in experiments with “vacuum tubes” it is not easy to ensure perfect constancy of the accompanying circumstances.

To test this conclusion we extended the range of our observations by varying the value of C as much as from 1 to 135.

In the paper are given the original measurements themselves, not the mean results, in order that the discrepancies in the readings obtained for V when C was kept as constant as our powers of control permitted, might be compared with the variations, such as they are, in the values of V when the circuit was purposely varied so as to produce currents of different strengths. Our observations show clearly that discharge through rarefied gases cannot be at all analogous to conduction through metals; for a wire having a given difference of potential between its ends can permit one—and only one—current to pass; whereas, from the measurements obtained it became evident that with a given difference of potential between the terminals of a given vacuum tube, currents of strengths varying from 1 to 135 can flow. We are therefore led to the conclusion that the discharge in a vacuum tube does not differ essentially from that in air and other gases at ordinary atmospheric pressures—that it is, in fact, a disruptive discharge.

By fixing small rings of tinfoil to the glass near the places where the metal terminals are fused into the tube and connecting these rings to earth, we were able to cut off the leakage over the surface (which, in spite of precautions, is considerable), and prevent it from interfering with our measurements of the potential of the gas *inside* the tube.

(To be continued.)

NORTHERN BORNEO

SOME time ago (NATURE, vol. xviii. p. 454) we were able to give a few particulars respecting the acquisition, by a British association, of a considerable portion of Northern Borneo, a region which has never yet been thoroughly explored. Under the title of “North Borneo,” the promoters of this association have just printed for private circulation a 4to volume, containing a sketch of the territory of Sabah, lately ceded to them, and a report on various portions of the same by a Ceylon planter, which are accompanied by an analysis of soils and three appendices. The volume also contains two maps of Borneo, but the details given therein about the northern part are necessarily meagre.

The territory of Sabah comprises an area of some 18,000 square miles, possessing the great advantage of a coast-line of 500 miles from the Kimanis River on the north-west coast, to the Sibuco River on the east side of the island; it has the finest and almost only good harbours in Borneo, viz., Gaya Bay, Ambong, and Ousukan Bay on the west, and Sandakan Harbour on the east coast, the first and last named of which will, no doubt, become of great importance, especially if it be true that there is coal close at hand. The whole of Sabah is traversed by a mountain range of 5,000 to 8,000 feet in height, which culminates in the Kini Balu mountain, 13,700 feet high. To the east of this is the supposed position of the Kini Balu Lake, which no European has yet visited. On the shores of the lake, according to native reports, there are many villages of Ida'an, who cultivate cotton, tobacco, &c., and are said to be peaceful and industrious. There are numerous rivers on the north-west coast, but owing to the proximity of the high mountain ranges they are said to be only navigable by light craft; on the east coast, however, there are several splendid rivers, the Paitan, Sibuco, and Kinabatangan, the latter of which is believed to be navigable by large steamers for several hundred miles. As far as has been at present ascertained, the spurs and slopes of the Kini Balu range seem well fitted for the cultivation of coffee, tea, and cinchona, and the level country on the banks of Kinabatangan for sugar, indigo, tapioca, tobacco, cocoa, cotton, and rice. The Sabah territory is believed to be but sparsely peopled, the total population being estimated at 150,000 to 200,000; the interior is inhabited by descendants of the aborigines, called variously Muruts, Dusuns, or Ida'an, and corresponding in their external appearance in many respects to the Dyaks of Sarawak and the southern parts of the island, though they are of a lighter hue. The climate of the region is believed to be very favourable; in the plains and low-lying lands near the sea and rivers an invigorating breeze is generally felt during the day, the thermometer seldom ranging beyond 86°, while the nights are cool, with a temperature sometimes below 70°. No data are yet available in regard to the rainfall, but it is believed to be very similar to that of Ceylon. The soil is rich and fertile, and in many locali-